Power Systems Comparisons

Sandia National Laboratories
Intelligent Systems and Robotics Center

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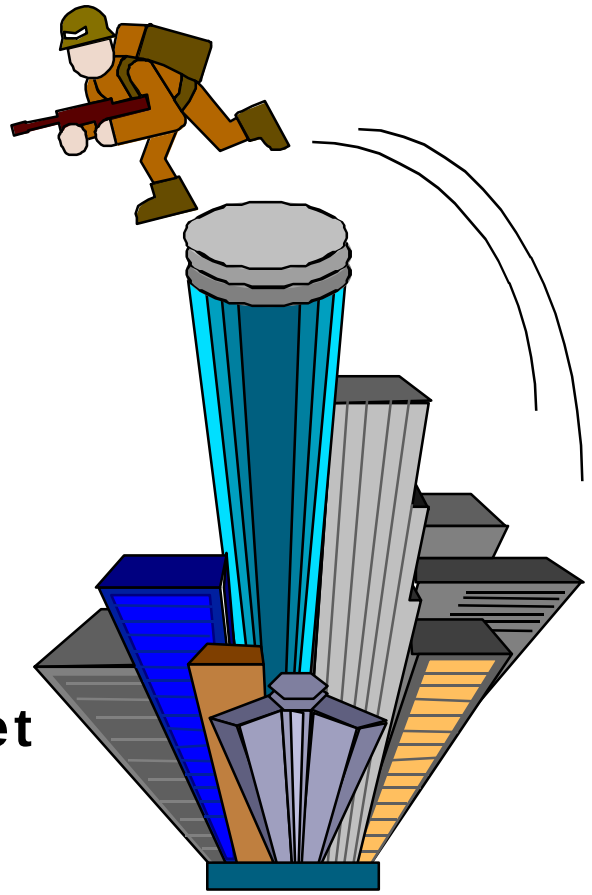
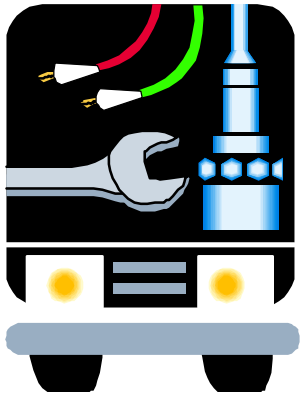
Soldier Enhancement Constraints

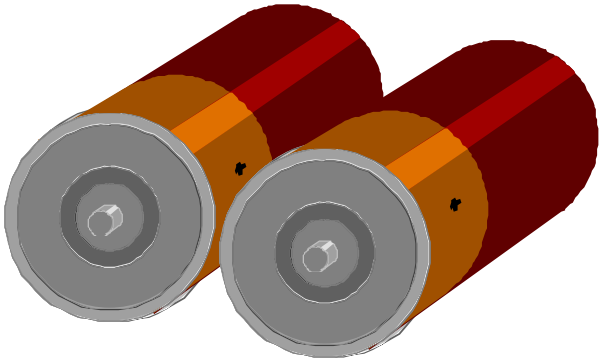
- Better than dinner
- Weighs nothing
- Takes up no space
- Lasts forever
- Has enough power to leap tall buildings in a single bound
- Is faster than a speeding bullet
- Can't have it all



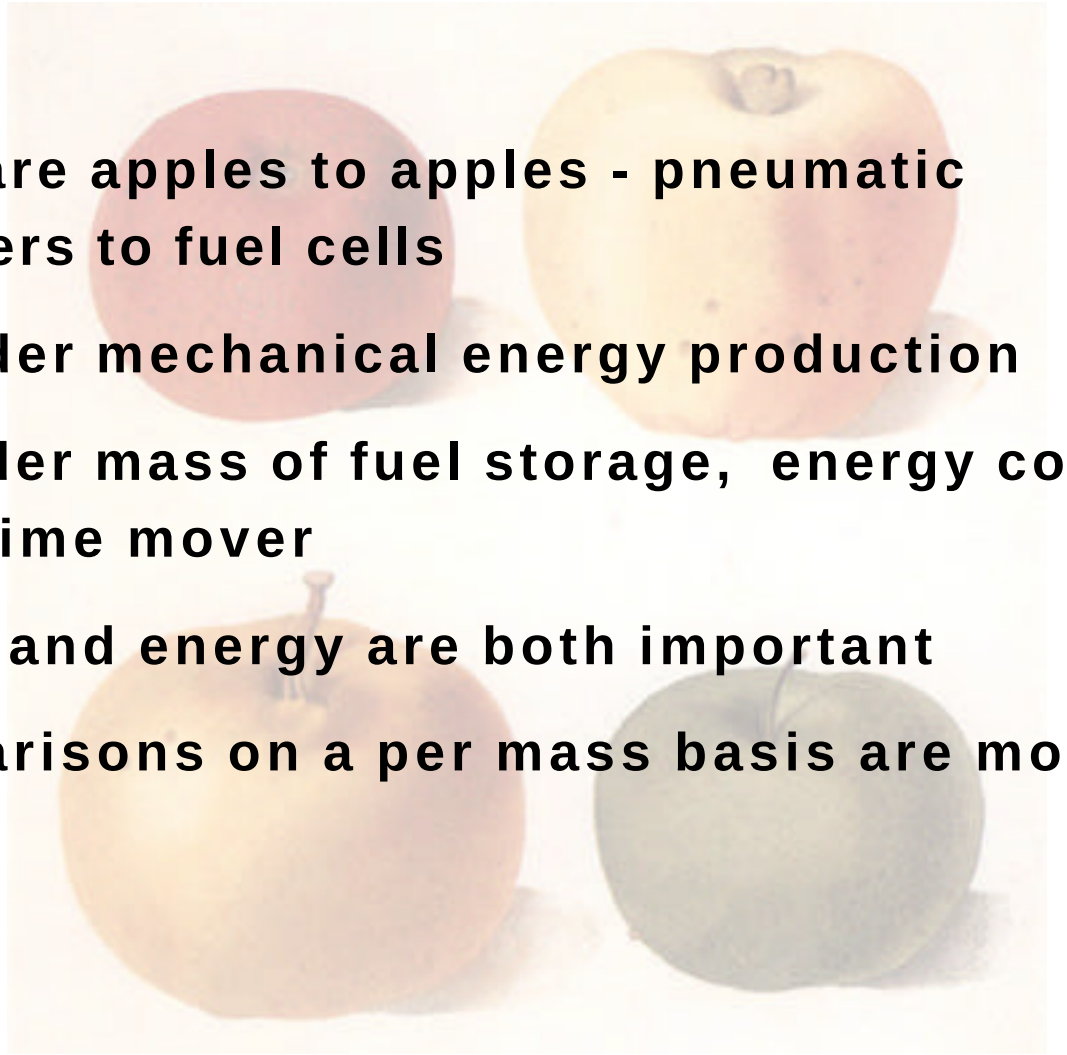
Many Potential Power Sources

- Pneumatic cylinders
- Internal combustion engines
- Elastic spring elements
- Flywheels
- Fuel cells
- Batteries
- Photovoltaics





System Comparison Basics

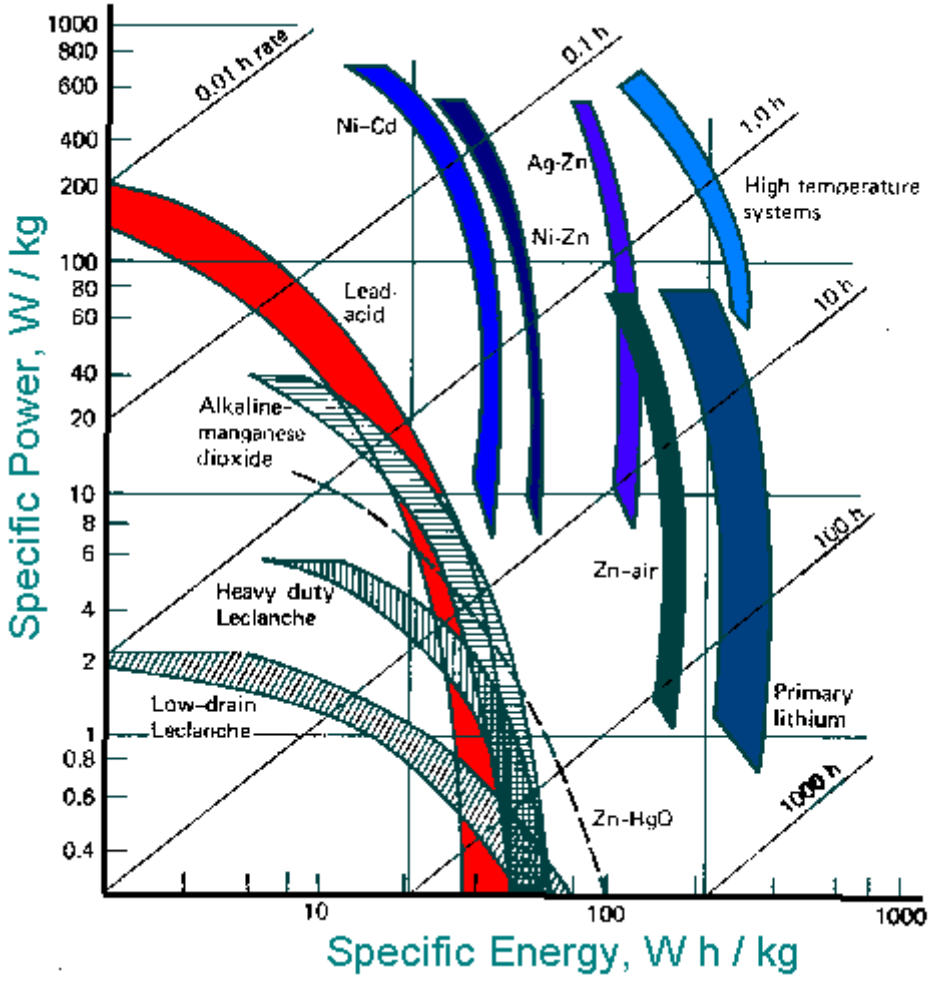


- Compare apples to apples - pneumatic cylinders to fuel cells
- Consider mechanical energy production
- Consider mass of fuel storage, energy converter, and prime mover
- Power and energy are both important
- Comparisons on a per mass basis are most useful

Power System Components

System Type	Storage	Converter	Prime Mover
Pneumatic	Pressure vessel	Cylinder	Cylinder
Internal combustion	Fuel tank	Engine	Engine
Elastic element	Elastic element	Elastic element	Elastic element
Flywheel	Flywheel	Flywheel	Flywheel
Fuel cell	Pressure vessel	Cell stack	Electric motor
Battery	Battery cell	Electric motor	Electric motor
Photovoltaic	None	Photo cells	Electric motor

Ragone Plot for Battery Comparisons



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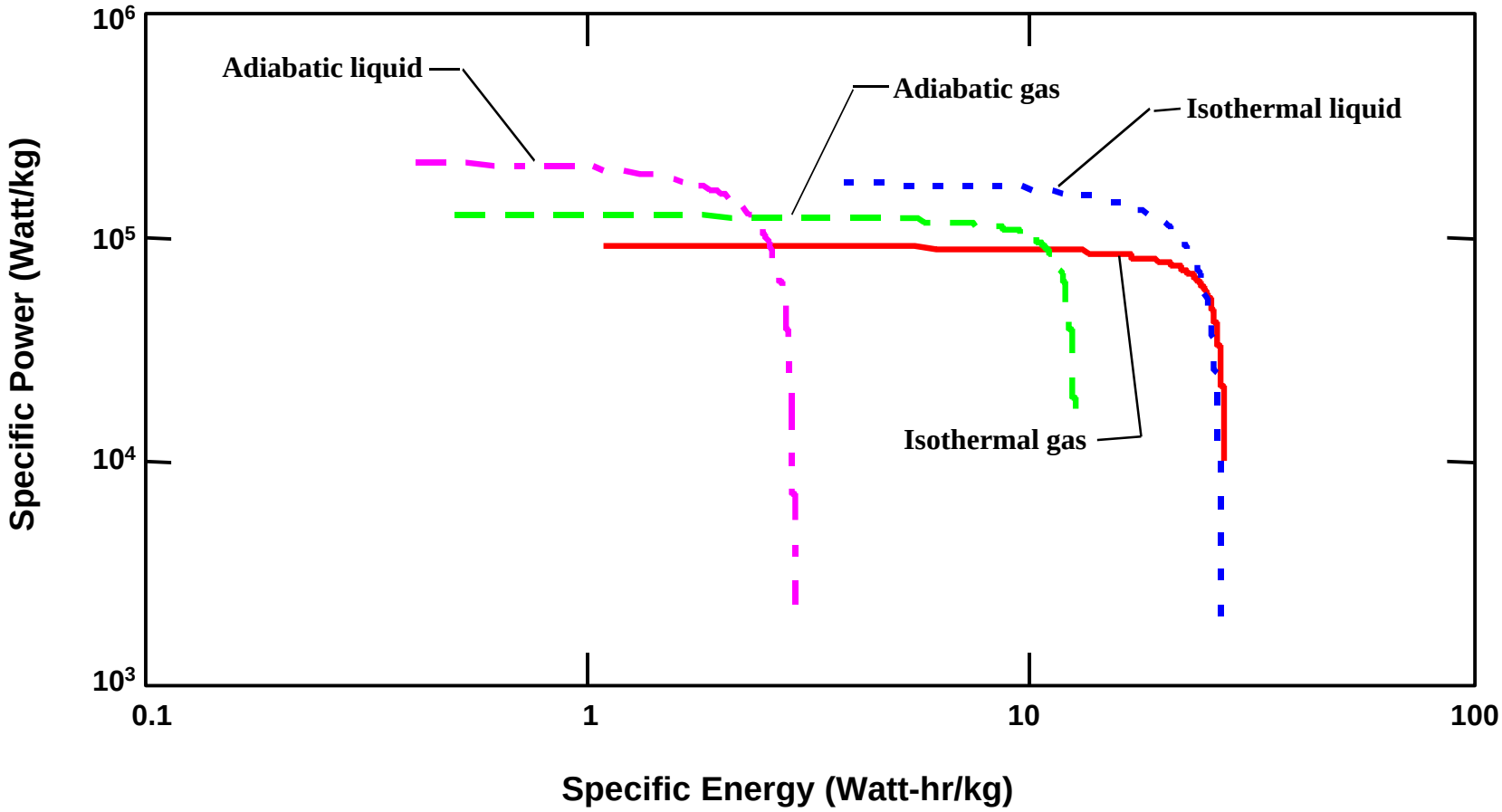
Compressed Gas Analysis

- Adiabatic and isothermal expansion
- Noncondensing (3000 psi H_2) and liquid (1100 psi CO_2)
- Simple cylindrical tank (σ=100,000 psi, ρ=2.7 gm/cc)
- Work extracted in cylinder actuator
- Actuator speed limited by application

Compressed Gas Results



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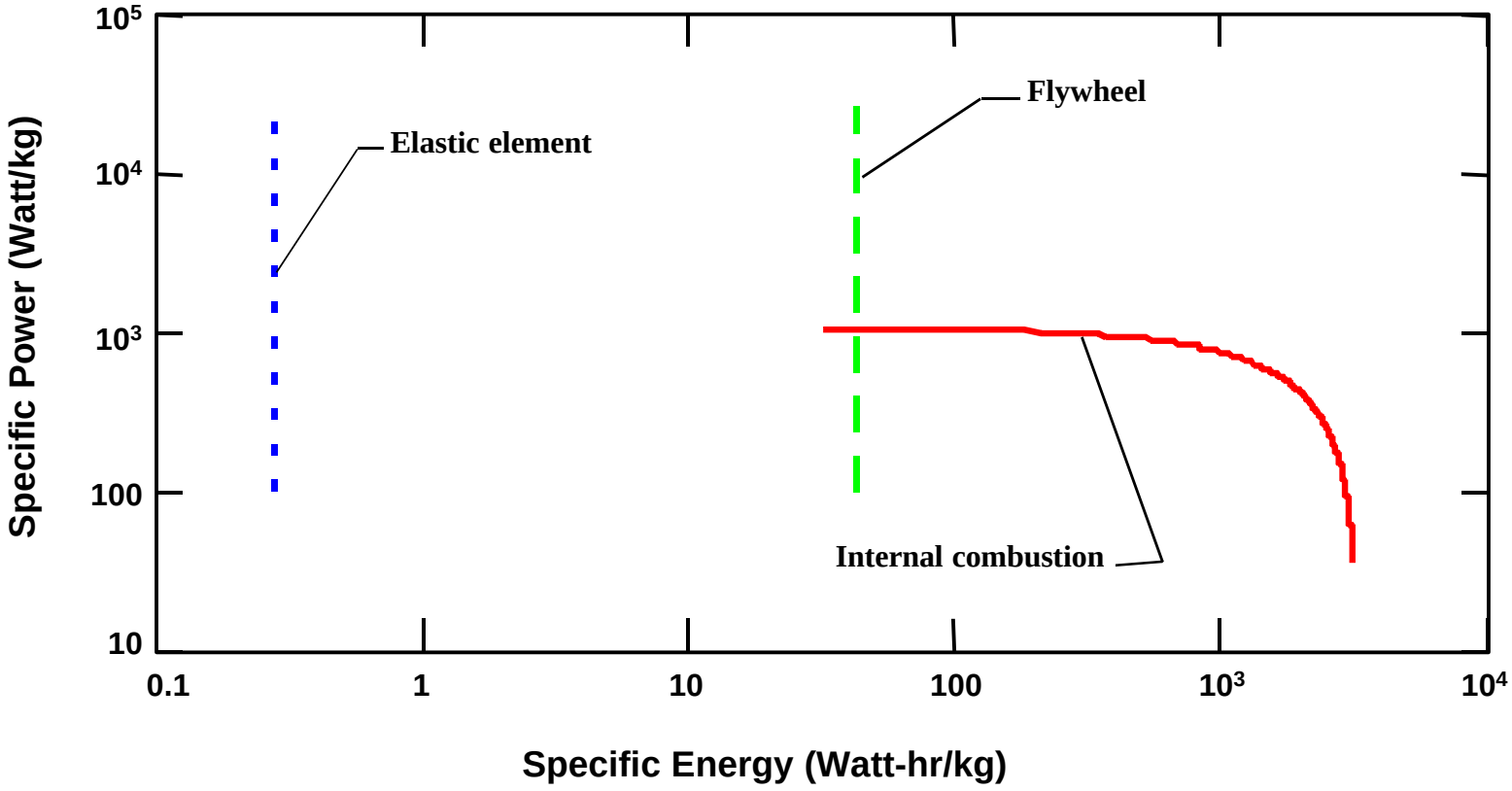
Internal Combustion Analysis

- Thermal efficiency of 25%
- **Specific weight of 1.5 lbs/hp**
- **Negligible fuel tank weight (<< fuel weight)**

Spring/Flywheel Analysis

- Allowable stress: 200,000 psi
- Material density: 2.7 gm/cc
- Elastic modulus: 50 x 10^6 psi
- Solid rotating disk
- Uniformly strained spring element

Combustion/Spring/Flywheel Results



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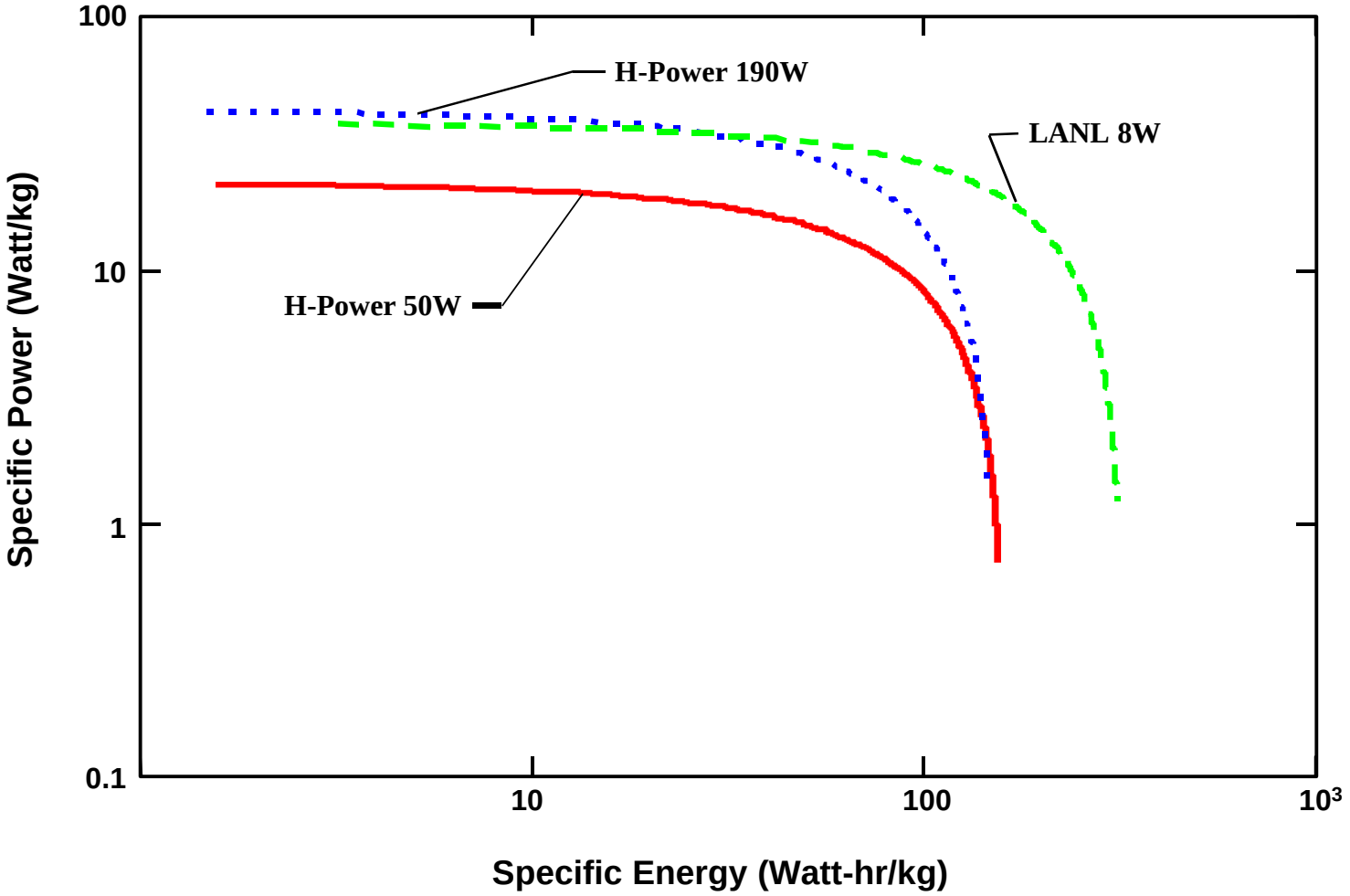
Fuel Cell Analysis

- H-Power 50 and 190 watt, LANL with hydride storage
- Prime mover is electric motor at 200 Watt/kg

Fuel Cell Results



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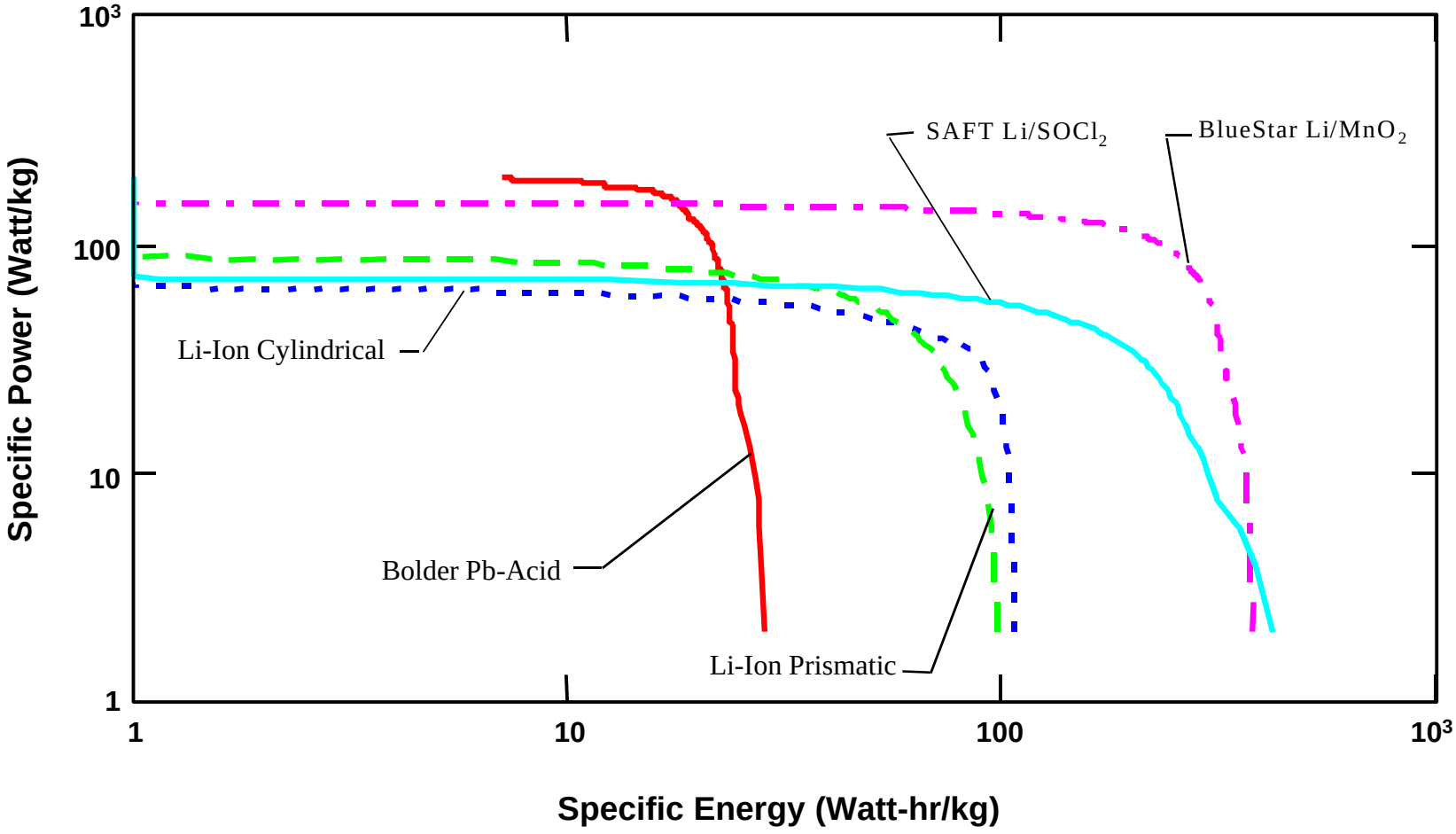
Battery Analysis

- BlueStar Li/MnO_2 15Ah Pouch Cell
- Ultralife Li/MnO_2 10Ah Cylindrical D-Cell
- SAFT Li/$SOCl_2$ spirally wound 12Ah D-cell
- Lithium-ion cylindrical battery
- Lithium-ion prismatic battery
- Bolder High-Power Lead Acid Battery
- **Prime mover is electric motor at 200 Watt/kg**

Battery Results



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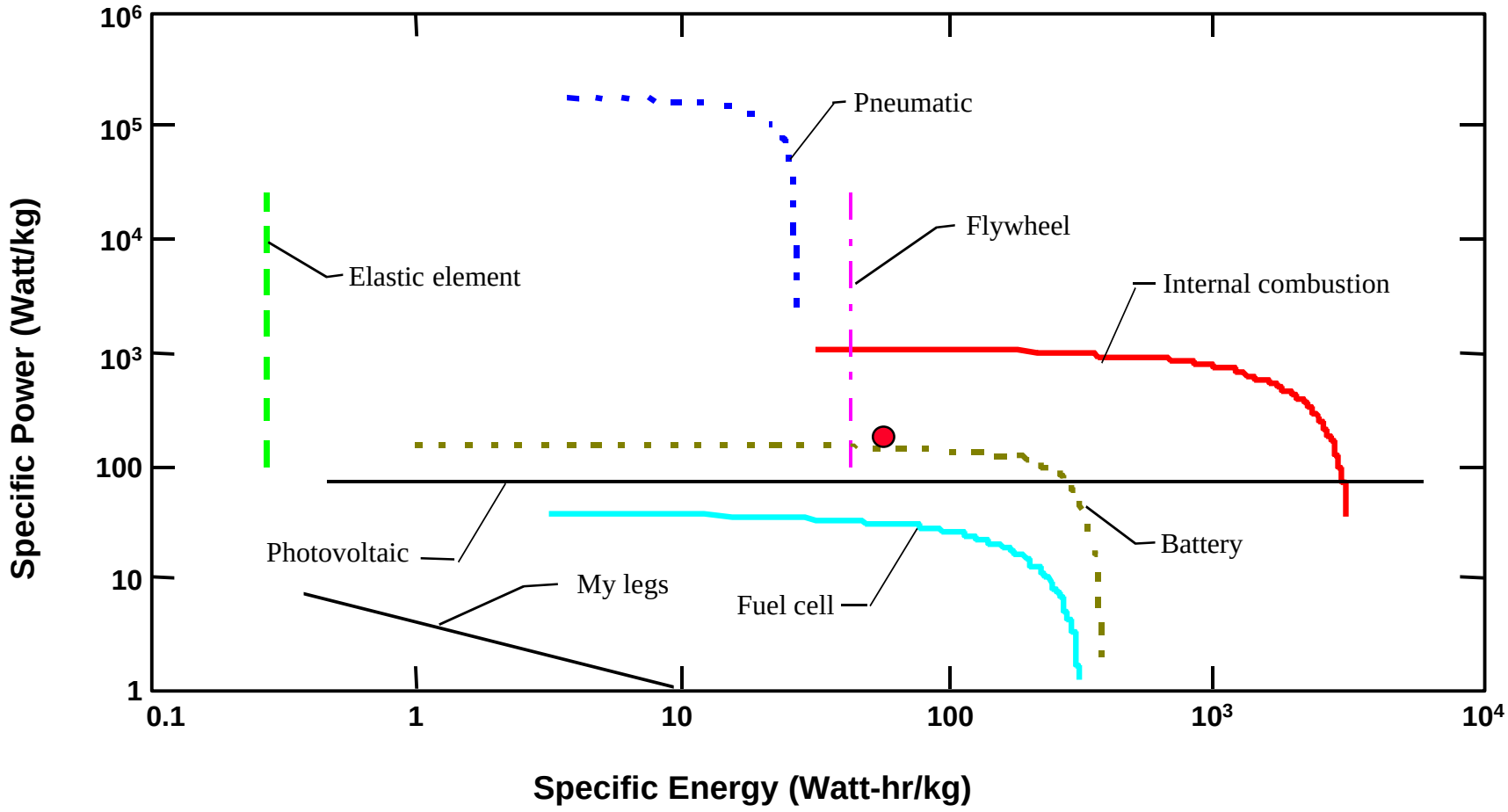
Results Summary



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Conclusions

- Ragone plots provide a quick overview
- Multiple potential systems exist
- Specific needs can easily lie on the edge of technology
- If it wasn't tough, we would not be doing it